Geotechnical Aspects of Underground Construction in Soft Ground, Kastner, Emeriault, Dias, Guilloux (eds)
 ISBN 2-9510416-3-2

The use of piling and propping for the protection of buildings beside deep excavations: case studies from Taipei, Taiwan

Bin- Chen, Benson Hsiung
FaberMaunsell Ltd, United Kingdom (former University of Bristol)

David F. T. Nash
University of Bristol, United Kingdom

Chun- Hung Chen
Department of Rapid Transit Systems, Taipei Municipal Government, Taiwan

Richard, N. H. Hwang
Moh and Associates Inc., Taipei, Taiwan

ABSTRACT: Due to the high population density in metropolitan area in Taipei, deep excavations are frequently used for both public infrastructure and private sector construction. Such excavations often result in large settlement of nearby buildings which naturally concerns their residents. The ground conditions in Taipei are generally lightly over consolidated clays and silts with a high water table and several measures are commonly adopted to reduce the settlement of adjacent buildings beside excavations. Amongst these, the installation of temporary props to the facades of buildings beside excavations is not an unusual sight. Sometimes an additional row of piles is installed between the perimeter wall and the adjacent building. In this paper, the records of settlement for several buildings beside excavations in Taipei is presented, and the effectiveness of protective propping and piling is assessed.

1 INTRODUCTION

Due to the high population density in metropolitan area in Taipei, deep excavations are frequently used for both public infrastructure and private sector construction. Of course, buildings are often located very close to such excavations and in the soft ground prevalent in Taipei, damage to adjacent structures is not unknown. Moh and Chin (1993) reviewed current experience in Taipei and described various measures that might be considered to reduce building movements, including propping, underpinning, compaction grouting, cut-off-piling and building strengthening measures, as shown in Figure 1. Amongst these, propping and cut-off-piling are commonly utilised in Taipei. This paper contains brief descriptions of two excavations on the Nankang Line of phase 1 of the Taipei Rapid Transit System (TRTS) where there was props and piling were installed to protect adjacent structures. The effectiveness of these measures is evaluated.

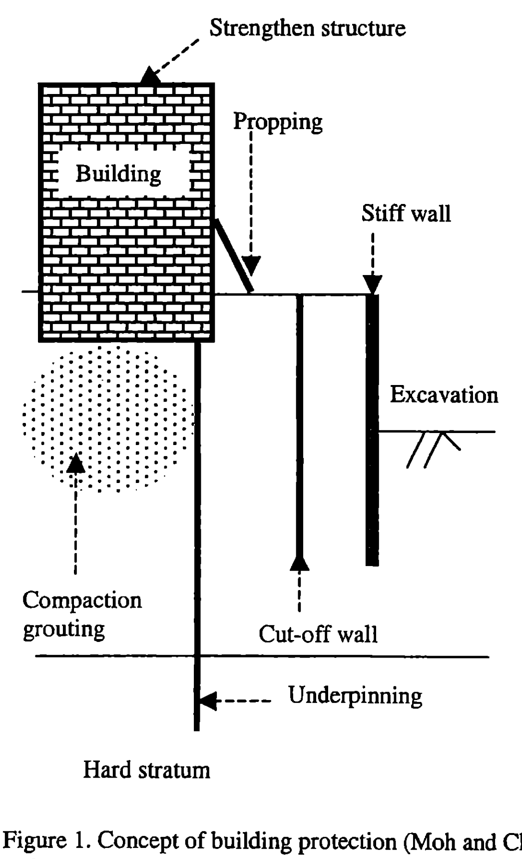

Figure 1. Concept of building protection (Moh and Chin, 1993)

2 THE SITE

Yung- Tsung (BL14) station on Nankang Line of TRTS is located on Chung- Hsiao East Road in Taipei City, near Hsinyi project township. A plan and cross section of the excavation at BL14 station are shown in Figures 2 and 3. For the main station, diaphragm walls 1.2m thick, 38m deep were installed to retain the 16.7m deep excavation. Beside one end of the station, a 21.1m deep excavation was dug for an exit to the underground station (JDB-Exit A) prior to construction of the multi-storey Joint Development Building. A cross section is shown in Figure 4. JDB-Exit A was constructed bottom-up but BL14 station was built top-down with its central concourse level slab constructed after installation of the bottom slab. The major soil strata here are the Sung-Shan Formation consisting of very thick lightly over-consolidated clay and silt which overlie gravel at 35m depth (see Figure 2 and 4). The undrained shear strength at the base of the final excavation was generally 50 to 70 kPa, and the angle of shear resistance measured in consolidated undrained triaxial tests was 30°- 34°. Below the gravel layer there is a layer of weak sandstone.

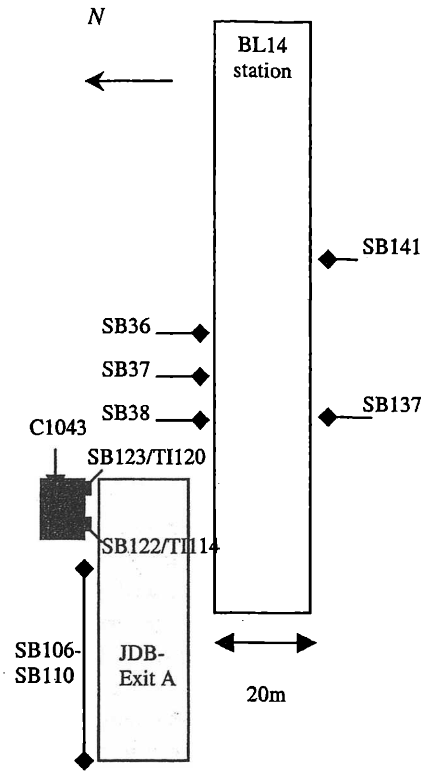

Figure 3. The locations as well as instruments of BL14 station and JDB- Exit A sites

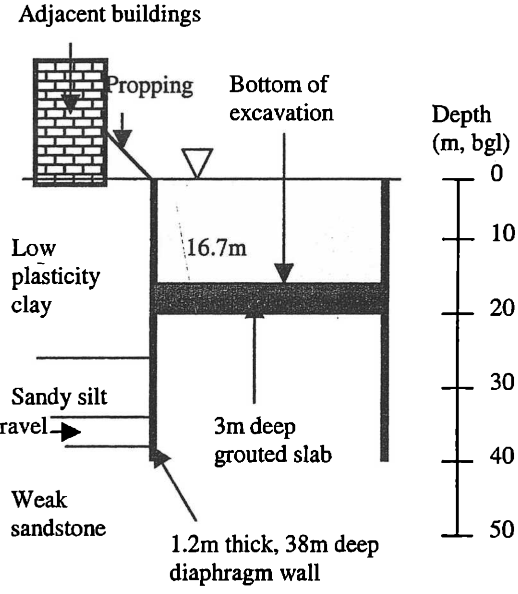

Figure 2. Cross section through the excavation for BL14 station

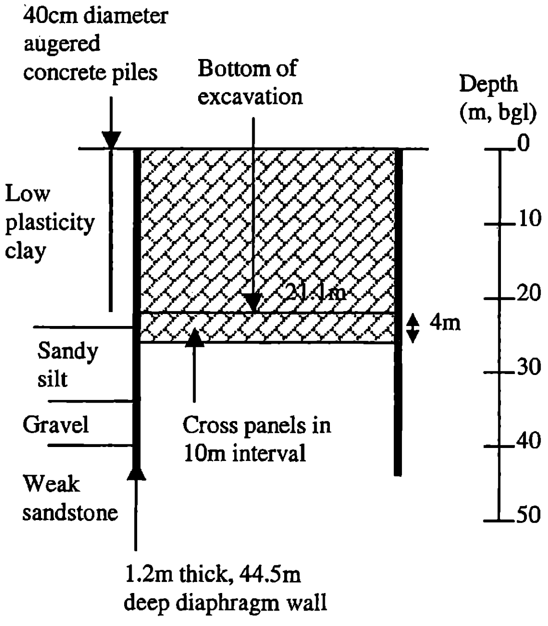

Figure 4. Cross section through the excavation for JDB- Exit A

3 THE USE OF PILING AND PROPPING FOR DEEP EXCAVATIONS IN TAIPEI

Some buildings supported on shallow foundations were within 3m from the excavation at BL14 station and JDB-Exit A (Moh and Associates Inc., 1998 and 2000a). Here steel props were used to provide additional support. The installation of all props was carried out after the completion of the 1st stage shallow excavation. Figure 5 shows the props placed to support a 4-floor house, C1043, beside JDB-Exit A, which was already tilting severely before the start of any construction. This building was a reinforced concrete framed structure founded on shallow pad foundations. The props bore onto the top of the diaphragm wall and were pre-stressed in an attempt to minimize movement. Additionally, in a further attempt to limit the damage of building C1043, a series of contiguous piles was installed between the diaphragm wall and this house.

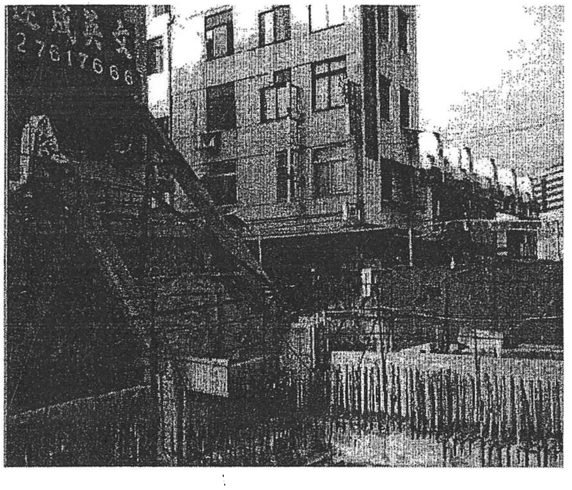

Figure 5. Propping of building C1043 at JDB- Exit A site

4 OBSERVATIONS

The building response to excavation-induced settlement depends on the pattern of ground movement as well as the stiffness of the structure. Boscardin and Cording (1989) and others showed whereas building tilt is relatively innocuous, horizontal strains and distortion may lead to damage of the structure. The building settlements resulting from the excavation were observed at BL14 station and JDB- Exit A sites. The locations of the settlement monitoring points mounted on buildings (denoted SB here) are given in Figure 3. Adjacent to the north side of BL14 station, the buildings were supported by raft foundations beneath a single basement. No propping was used. The building settlements increased from a measured 20mm at the start of main excavation to 30mm at the completion of the excavation, as shown in Figure 6. (The slight jump in the readings is probably associated with a change of monitoring team). Lateral movement of the diaphragm wall here reached a maximum of about 30mm.

In contrast, the settlements of buildings on the opposite (south) side of the excavation were much larger, with the maximum building settlements increasing from around 20-25mm before the main excavation to 80-110mm at the end of the excavation, as presented in Figure 7. These buildings were founded on shallow strip foundations and propping was installed to support their facades. Similarly the settlement of some un-propped buildings on raft foundations near the JDB-Exit A site increased from 20-35mm after diaphragm wall installation to 60-90mm by the end of the excavation (see Figure 8). The most likely reason that building settlements were much larger on the south side and near the west end of the site is that a basement was being excavated for a 12-floor building near southwest corner of BL14 station at almost the same time as the excavation for the station.

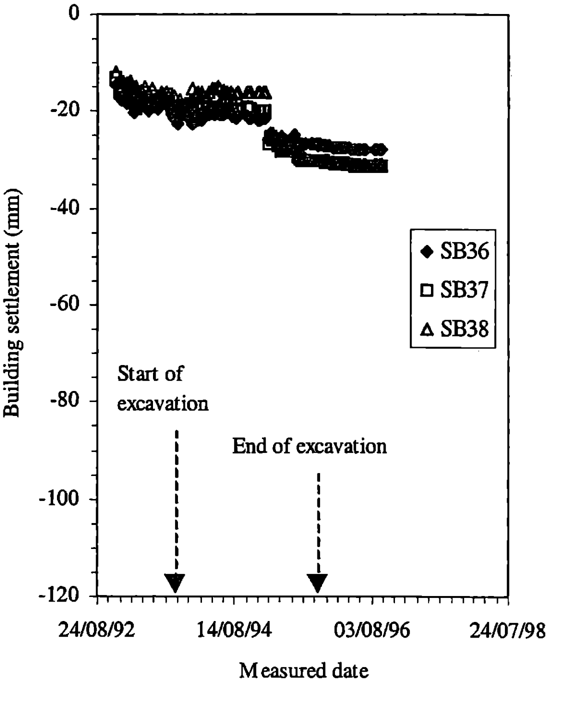

Figure 6. Observed settlement of buildings on the north side of the BL14 station (without propping)

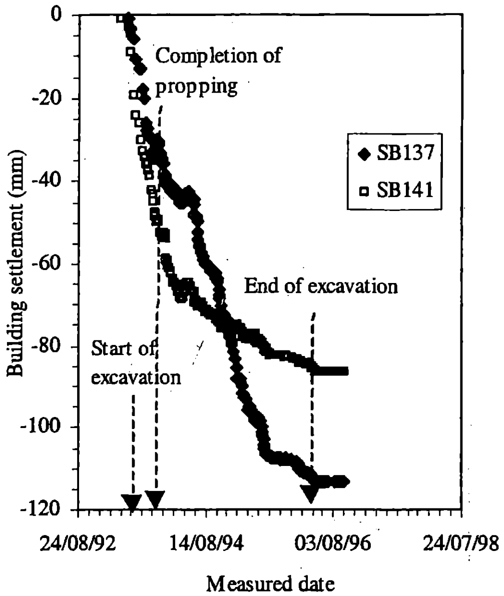

Figure 7. Observed settlement of buildings on the south side of the BL14 station (with propping)

5 DISCUSSION

As illustrated above, propping and protective piling were utilised at the BL14 station and JDB-Exit A sites. The effectiveness of these protection measures is assessed in the following sections.

5.1 The use of propping to support buildings adjacent to excavations

Moh and Associates Inc. (1998) reported that at BL14 station, up to 40mm building settlement had occurred during wall installation and the 1st stage shallow excavation. In attempt to prevent the development of excessive movements at later stages, propping was carried out to support the nearby buildings. Despite these measures, the observations of the settlement points SB137 and SB141 at the south end of the BL14 station show that the buildings continued to settle markedly after the installation of the propping, and reached about 80-110mm by the end of the excavation, as shown in Figure 7. Clearly, the propping here was insufficient to prevent significant building movement. Limited numbers of steel props were installed from the top of the wall to the buildings nearby to support their facades, and some of the structural loads were transferred to the diaphragm wall.

Figure 9 presents the settlements observed at building C1043, which is close to the excavation for JDB-Exit A. Despite installation of the props (see Figure 5) building C1043 continued to settle, and movement reached 50-70mm by the end of the excavation. Examination of Figures 8 and 9 shows that there is only a limited difference between the settlement observed at C1043 and that observed at other un-propped buildings beside JDB-Exit A. Observations of building tilt were also made at C1043 (see Figure 10). This shows that building C1043 had rotated by 3×10^{-3} (ie 1 in 300) by the end of monitoring.

Figure 11 shows the building settlements observed at a nearby underground station, BL12, constructed in similar ground conditions to those at BL14, and to a similar depth and width. At this site there were similar adjacent foundations but propping was not utilised. Figure 11 shows that the maximum building settlement of some close structures reached 120mm, which is approximately the same as that observed at BL14. Moh and Associates Inc. (1995) reported the maximum tilt of structures surrounding BL12 station was generally 2×10^{-3} to 4×10^{-3}.

The above evidence from JDB-Exit A and BL14 and BL12 stations, strongly suggests that this type of structural propping is not able to restrict the movement and rotation of buildings adjacent to a deep excavation.

The observations in Taipei contrast with behaviour observed during the construction of a new underground station beneath the Circle and District lines at Westminster station in London (Stone and Crawley, 1999), and construction of a new tunnel beneath a 33m wide, 270m long, 3-level underground shopping mall and an existing subway in Nagoya City, Japan (Iwasaki et al., 1994). At Westminster full protective underpinning was carried out to take the load of existing station structure to the deeper harder soil strata before the start of excavation. The structural load was carried via a transfer slab into a number of 55m deep piles of up to 3m diameter. While some significant movements occurred during installation of the piles which necessitated close control of the track level, the subsequent movements of the station during excavation beneath it were small. At Nagoya City the shopping mall and subway were first underpinned using 15m long 1m diameter cast-in-place concrete piles installed into a layer of stiff clay before the tunnel was excavated and constructed between them. Here the maximum settlements of the structures reach 4mm at the end of the excavation.

At both sites in London and Nagoya City, underpinning piles were installed into the stiffer soil strata to transfer the load of the upper structure effectively. This contrasts with the façade propping at BL14 station and JDB-Exit A sites where probably only part of the facade load was carried down the diaphragm wall. Certainly such propping measures can be utilised to prevent building collapse. However unless the entire load of the adjacent buildings is completely transferred to stiffer ground at depth, structural propping of the façade does not appear to eliminate large building movements and distortions resulting from the ground displacement induced by the excavation.

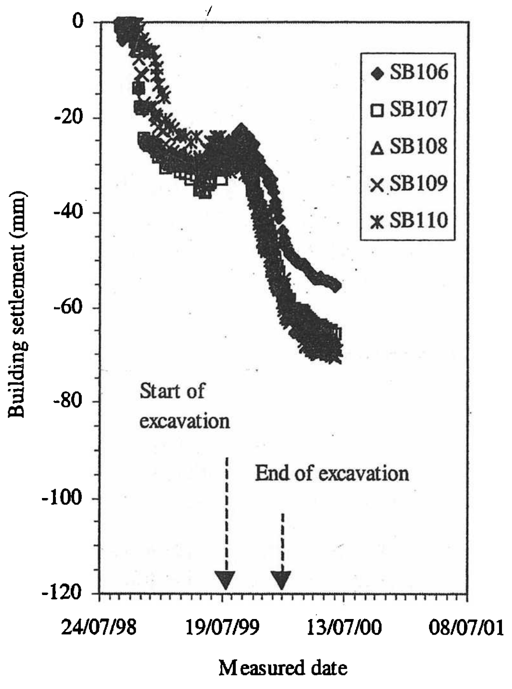

Figure 8. Observed settlement of buildings beside JDB- Exit A (without propping)

5.2 Piling for the house protection

Woo (1996) suggested that the piling installed between the perimeter wall of an excavation and the adjacent buildings may be able to reduce the lateral pressure on the perimeter wall and thus reduce the movements caused by the excavation. Such piling was carried out at two different sites, JDB Exit-A and Mingshen Water tank (Moh and Associates Inc., 2000b). At the site of JDB-Exit A, in addition to propping building C1043, a row of 20m deep 40cm diameter contiguous augered concrete piles was installed between the building and the diaphragm wall (see Figure 4). Unfortunately these additional piles were unable to arrest the ground movement – and indeed their installation may itself have made the problems worse. The piles were floating in the soft clay since their toes were above the hard soil strata at the site of JDB-Exit A.

At the site of the Mingshen water tank, piling was installed along one side of the excavation in an attempt to protect of adjacent buildings. A row of 45cm diameter jet-grouted piles was installed from to 21m below ground level before the start of the excavation. However, these jet grouted piles also floated in the soft clay, and field monitoring showed they were not able to reduce the lateral deflections significantly. In a further attempt to reduce movements a second row of 60cm diameter deep mixing cement piles were installed to 14m bgl was installed between the previous jet-grout piles and the buildings as the main excavation progressed. However, even these piles did not reduce the movements and some building settlements reached 270mm by the end of construction.

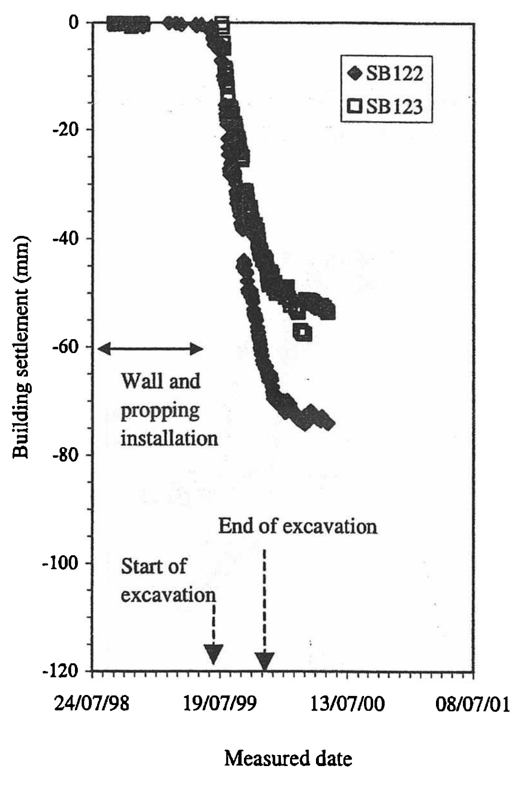

Figure 9. Settlement of house C1043 induced by the excavation at JDB- Exit A (with propping)

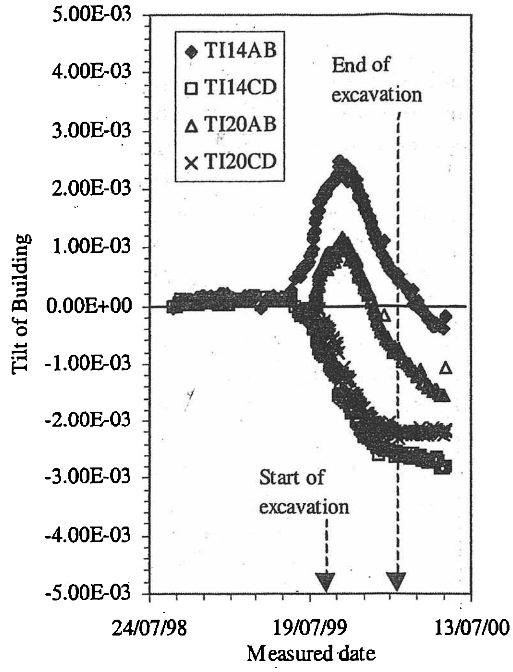

Figure 10. Observed tilt of house C1043 beside JDB- Exit A (with propping)

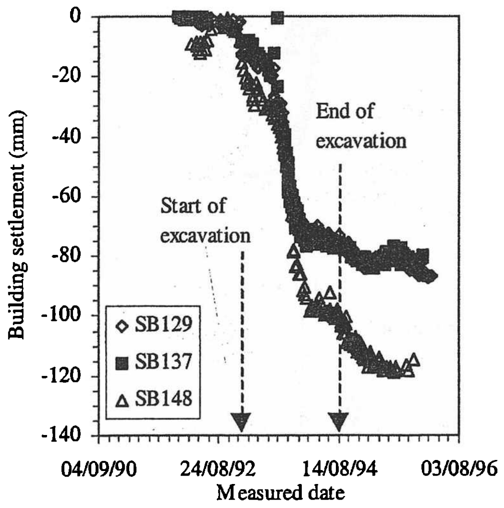

Figure 11 Observed settlement of buildings at BL12 station (without propping)

6 CONCLUSION

From these field observations at deep excavations in soft clay ground conditions in Taipei, it may be concluded the propping of the facade of an adjacent building off the top of a diaphragm wall was not effective in reducing the building settlement at these sites. This is mainly because the support system as a whole is not sufficiently stiff or extensive that building loads could be transferred to stiff ground at depth. Similarly the installation of an additional bored pile wall between the perimeter wall of the excavation and the adjacent buildings is not sufficiently stiff that ground movements associated with the excavation are reduced. It is also clear that important buildings require complete underpinning to isolate them from movement of the underlying ground.

ACKNOWLEDGEMENTS

The first author was supported by a research scholarship from the University of Bristol. The authors are also grateful to the Department of Rapid Transit Systems for granting permission to publish the data presented herein. The field data provided by Moh and Associates Inc., Taipei, Taiwan is appreciated.

REFERENCES

Boscardin, M. D. and Cording, E. J. (1989) Building response to excavation-induced settlement, ASCE, *Journal of Geotechnical Engineering*, Volume 115, No. 1, 1-21

Iwasaki, Y., Watanabe, H., Fukuda, M., Hirata, A. and Hori, Y. (1994), Construction control for underpinning piles and their behaviour during excavation, *Geotechnique* 44, No. 4, 681- 689

Moh, Z. C. and Chin, C. T. (1993), Recent developments in deep excavation in soft ground, International conference on geotechnical engineering and earthquake resistant technic in soft area, Shenzhen, China, 1- 14

Moh and Associates Inc. (1995), Final report for the ground monitoring data for Lot CN256 on Nankang Line, Taipei MRT System, Moh and Associates Inc., Taipei, Taiwan (In Chinese)

Moh and Associates Inc. (1998), Final report for the ground monitoring data for Lot CN258 on Nankang Line, Taipei MRT System, Moh and Associates Inc., Taipei, Taiwan (In Chinese)

Moh and Associates Inc. (2000a), Final Report for the Ground Monitoring Data for Lot CN258C on Nankang Line, Taipei MRT System, Moh and Associates Inc., Taipei, Taiwan (in Chinese)

Moh and Associates Inc. (2000b) Geotechnical engineering consultant report for the excavation at Mingshen Water Tank, Moh and Associates Inc., Taipei, Taiwan (in Chinese)

Stones, C. S. and Crawley, J. D (1999), Westminster Station, London- deep excavation below an operation railway: construction the new Jubilee Line Station interchange hall, 12th European Conference of Soil Mechanics and Geotechnical Engineering, Geotechnical Engineering for Transportation Infrastructure, edited by Barends *et al.*, Amsterdam, Volume 1, 1- 6

Woo, S. M. (1996), Some aspects of deep excavation in Taiwan, 12th Southeast Asian Geotechnical Conference, 131- 141, Kuala Lumpur, Malaysia